Design of Apparatus to Facilitate Rapid Measurements With the Oscillograph

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Design and Construction of Apparatus to Facilitate Rapid Measurements With the Oscillograph

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THE DESIGN AND CONSTRUCTION OF APPARATUS TO FACILITATE RAPID MEASUREMENTS WITH THE OSCILLOGRAPH.

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The wave form of the alternating current or emf., though readily mathematically analysable in a few cases where the constants of the circuit - resistance, inductance and capacity - are known, yet in the great majority of cases as found in the large field of present day application is not thus analysable. The reason obviously, is due to a lack of complete information of the conditions of the circuit. Thus iron hysteresis is effective in distorting the wave form of transformer current. A mathematical analysis of such distortion is difficult because the law connecting magnetization to induction cannot be expressed so as to hold mathematically good at all times. Hence the conditions of a circuit in which iron is placed is such, as far as inductance is concerned, as to preclude the determination of the wave form. Some other factors, affecting similarly the conditions of a circuit are: the counter emfs. of arcs, the pulsating inductance of alternators, the hunting of generators working in parallel and surgings in transmission lines, caused by switching or short circuit, the latter producing wave forms distinct for a monentary period only. It is obvious, therefore, that if the complete information of the conditions of a circuit are not obtainable, the next best thing to do is to secure a registration of the resulting wave form, derive the necessary inferences direct from it, set up impirical formula corresponding to the external conditions if the circuit so far as known, or, if possible work backwards from the wave form to a determination of the inherent conditions of the circuit giving rise thereto. To obtain such registration

of wave form is the function of the Oscillograph.

This instrument in its two forms - the vibrating strip and vibrating loop type - is the work primarily of Blondel, first announced in 1893*. The usefulness of the instrument was predicted by him of which he states at a latter date, "As I announced at that time (1893) these machines (oscillographs) appeared to me to be destined to play in the study of alternating currents a role similar to that of the indicator with reference to the steam engine".** It is recognised that the efficiency of alternating current machinery of almost all discriptions varies with the shape of the wave form. A study of the wave form of transmission lines tending toward resonance conditions will show up these characteristics, whence, knowing them, provision may be made against breakdown. A knowledge of emf. wave forms will reveal the maximum strain to which insulation is subjected, especially of those wave forms that are caused by surgings. This sphere of commercial usefulness of the oscillograph has urged on its development to a commercial form of instrument, capable of being handled by one having ordinary skill in the handling of instruments.

It is not our purpose, however, to treat of the oscillograph (see references given below) except to state that the one with which

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* Comptes Rendus, April 1893.

** L'Industrie Electrique

Trans. Electrical Review (N.Y.) May 24, 1899.

Oscillographs (Robinson, L. F.)

A.I.E.E. April 28, 1905.

Oscillograph, Instructions to Use (General Electric Co.)

the authors have to do is of the three element, vibrating loop, D'Arsonval galvanometer type, provided with an optical system and apparatus for both visual observation and photographic registration of the wave form of the sources under investigation - all put together and manufactured in a good commercial form by the General Electric Co. Further the free period of each element is guaranteed to be 5000 complete oscillations per second; the sensitiveness .003 amperes per millimeter deflection; the maximum allowable current through each loop .1 ampere; and the resistance of each loop 2. ohms (which resistance includes that of a mil. composition fuse, the latter being used instead of the 5 ohm gold fuse supplied with the instrument).

All electrical or magnetic variable phenomena which in any way can be made to produce a current proportional to their manner of variation, will have this manner of variation faithfully disclosed upon sending this current through an element of the oscillograph. But, if the current of the source under investigation is greater than .1 ampere, which it will be in the majority of cases, very obviously a portion of this current, never to exceed .1 ampere, must be shunted to an element of the oscillograph. A similar proposition may be stated relative to emfs., namely, that all electrical and magnetic variable phenomena which can be made to produce an emf. proportional to their manner of variation, will have this manner of variation faithfully disclosed upon applying this emf. to the terminals of an element of the oscillograph. But, if the emf. exceeds .2 volts (e,i, to cause a current exceeding.1 amp. to flow), very obviously, resistance must be introduced into circuit so as to reduce the emf. to a safe value (less than .2 volts at the terminals

of an element). It must be concluded, therefore, that a number of shunts and resistances are immediate requisites to carry out any investigation with the oscillograph. But in order that these investigations may be made with facility and rapidity, it is necessary that these shunts and resistances be placed in circuits having a permanent form, such as would be had by assembling them in some kind of a cabinet. The design and construction of such a cabinet, and of the circuits, shunts, resistances and necessary switches to be contained therein, has been carried into execution by the authors to fulfil the following requirements:

(1) That a minimum number of testing circuits be provided;

(2) That provision be made to register, with as large a deflection as possible, emfs. varying from 1 to 2000 volts (the maximum corresponding to a maximum A, C, effective emf. of 1400 volts approximately);

(3) That provision be made to register with as large a deflection as possible, currents varying from .01 to 300 ampers (the maximum corresponding to a maximum A, C, effective current of 200 amperes approximately);

(4) That provision be made to make the registrations quantitative as well as qualitative; and

(5) That the cabinet be made transportable on roller castors, whence the weight, a minimum.

(1) The minimum number of testing circuits to provide is suggested by three phase transformer work. Thus, there are three emfs. and three currents on the high side; and a similar number of emfs. and currents on the low side to be investigated. In

order that it shall not be necessary to disconnect each time a set of three registrations is made, twelve distinct testing circuits must be provided : six to be for emf. registrations, and six for current registrations.

(2) The potential circuits must be porvided with non-inductive resistances to reduce the emf. so that a current less than .1 ampere will flow. This current of .1 ampere, with the average field exertation supplied to the field electromagnets, and with the average tension on the vibrating loop, will produce the maximum deflection. While it is desirable that all registrations shall appear with a maximum amplitude of deflection, no matter what the actual magnitude of the emf. under investigation may be (e,i, anywhere between 1 - 2000 volts), nevertheless such deflections can only be obtained at a great increase in the number of switches necessary to shunt out of circuit the increased number of distinct resistances which would be necessary to adjust for a maximum deflection. Since the number of distinct resistances is to be kept a minimum, the six potential testing circuits must be divided into three high potential testing circuits, and three low potential testing currents, so that the necessary subdivision of resistance for low potential registration need not be duplicated in the circuits for high potential registration.

Though the desirability of a maximum deflection at all times is thus sacrificed to allow for a diminution of complexity, and of amount of apparatus, nevertheless with a division of the potential testing circuits into two groups as just indicated, with as small a number as three distinct resistances in each of the high potential circuits, and with four distinct resistances in each of the low

potential circuits, all deflections may be insured to be greater than 50% of the maximum possible, let the magnitude of the emf. under investigation be what it will.

For each of the low potential circuits, the set of resistance must contain a

TABLE I

(1)	250	ohm coil
(2)	500	" "
(3)	1000	" "
(4)	1000	" "

each, with the possible combinations, corresponding to a range of maximum emfs. (since 1000 ohms per 100 volts give a maximum deflection) as follows:

TABLE II

	Volts		Maximum Volts
(1)	15	to	25
(2)	25	"	50
(1 &(2)	50	"	75
(3)	75	"	100
(1 & 4)	100	"	125
(1 & 2)	125	"	150
(1 & 2 & 3)	150	"	175
(3 & 4)	175	"	200
(1 & 3 & 4)	200	"	225
(2 & 3 & 4)	225	"	250
(1 & 2 & 3 & 4)	250	"	275

For each of the high potential circuits, the set of resistances must contain a

TABLE III

(1) 5000 ohm coil

(2) 7000 " "

(3) 8000 " "

each, with the possible combinations, corresponding to a range of maximum emfs. (since 1000 ohms per 100 volts give a maximum deflection) as follows:

TABLE IV

	Volts		Maximum Volts
(1)	275	to	500
(2)	500	"	700
(3)	700	"	800
(1 & 2)	800	"	1200
(1 & 3)	1200	"	1300
(2 & 3)	1300	"	1500
(1 & 2 & 3)	1500	"	2000

(3). As the potential testing circuit must be fitted with potential reducing resistances, so the current testing circuits must be fitted with shunts, so as to shunt only a small portion of the current under investigation into the oscillograph. Because the range of currents to be provided for lies between .01 and 300 ampers, the shunts must have different resistances and current carrying capacities. In this instance also, in order to avoid duplication, the six current testing circuits must be divided into two groups of three each: one for "high" current testing, and the other for "low" current testing. (Here "high" refers

to large, and "low" to small currents).

The shunts, with their respective resistances such that no deflection shall be less than 50% of the maximum possible, for each of the low current circuits must consist of as follows:-

TABLE V

(1)	20	ohm shunt
(2)	10	" "
(3)	5	" "
(4)	2.5	" "
(5)	1.25	" "
(6)	.6275	" "
(7)	.31375	" "
(8)	.15687	" "
(9)	.07342	" "
(10)	.03671	" "
(11)	.01836	" "

each corresponding to a range of current (since, with the resistance of each element equal to 2 ohms, a potential difference across the shunt of .2 volts will produce a maximum deflection) as follows:

TABLE VI

	Ampers		Maximum Ampers
(1)	.005	to	.01
(2)	.01	"	.02
(3)	.02	"	.04
(4)	.04	"	.08
(5)	.08	"	.16
(6)	.16	"	.32

(7)	.32	"	.64
(8)	.64	"	1.28
(9)	1.28	"	2.56
(10)	2.56	"	5.12
(11)	5.12	"	10.24

In the case of each of the high current testing circuits, the shunts must consist of, as follows:

TABLE VII

(1)	.00918	ohm	shunt
(2)	.00459	"	"
(3)	.002298	"	"
(4)	.001149	"	"
(5)	.000574	"	"

each corresponding to a range of currents, as follows:

TABLE VIII

	Amperes		Maximum Amperes
(1)	10.24	to	20.48
(2)	20.48	"	40.96
(3)	40.96	"	81.92
(4)	81.92	"	163.84
(5)	163.84	"	325.68

From the rathur high resistance required by these shunts, one thing is very apparant, that the oscillograph is not a very sensitive instrument in comparison with some ammeters in ordinary use. A case may arise where it is necessary to register a current, the maximum value of which is .01 amperes. To obtain this registration would require the insertion of a 10 ohm shunt

into the main circuit, with the consequence, perhaps, that the conditions of that circuit would be somewhat altered. Had the gold fuse, supplied with the instrument, been left in circuit with each element, the energy required to obtain a given deflection would have been much greater. Even with the mil. fuse, used in place of the gold fuse, the necessary resistance of the shunts, as the tables show is high. Consequently, the construction of the shunts to have the necessary current carrying capacity, is limited as to smallness of dimensions.

(4). The value of the registrations of the oscillograph is greatly increased, if such registration is quantitative as well as qualitative. To draw a line across an indicator card, and state that the ordinate to this line means so many pounds steam pressure (which is practically done when it is said that the scale of the indicator spring is 60# to the inch, for example), makes it possible for one by scaling to tell the pressure at the important events of the engine cycle; and thus to determine whether his engine is running properly. Similarly, if across an oscillogram (a permanent record of same registration) a line could be drawn, the ordinate to which would mean so many volts or amperes as the case may be, the conditions of the circuit could be told with greater exactness.

Since the oscillograph to be used in this work is one employing the D'Arsonval principle, and since all resistances in the testing circuit are to be non-inductive, its deflections will be proportional to the emfs. and currents under investigation. Hence, if each element were calibrated it could be said at once

that so many millimeters deflection equaled so many volts or amperes. However, to determine the constants of each of the elements would be a futile undertaking, for in no two cases, probably, would the field strength and loop tension be the same. Therefore, the only feasible scheme to make a registration quantitative is to superimpose upon it, as soon after it is obtained as possible, a registration of a constant current, or, of a constant emf., as the case may be, of suitable intensity, but primarily of known value.

For the purpose of obtaining this quantitative registration upon an oscillogram to indicate the scale of amperes, direct current up to three hundred amperes is readily obtainable and readily measured with accuracy; but to indicate the scale of volts, it is not so easy to obtain D. C. potential up to 2000 volts, and still less easy to measure it with accuracy. In this latter case, therefore, the quantitative registration must be made at a voltage which can be readily obtained and easily measured. The ordinate to the resulting registration must then be multiplied, according to the law of multipliers, by a factor depending upon the resistances in the testing circuit at the time the registration of the source under investigation is made.

The factors governing the design of the testing circuits, with their resistances, shunts, and the means for obtaining quantitative registrations, have thus been detailed. It now remains to describe the construction of the apparatus and its dispostion in a cabinet to facilitate ease of operation.

An explanation of the actual testing circuits, together with the Oscillograph auxiliary circuits, will help at the start to

clarify matters. A schematic arrangement of these circuits is shown in fig. (1). It will be seen that there are twelve distinct testing circuits; six for obtaining emf. registrations, and six, for obtaining current registrations. Further, the six emf. testing circuits are divided into two groups of three circuits each; one, the high potential group, to be used where the maximum emf. lies between 275 and 2000 volts; and the other, the low potential group, to be used where the emf. lies between 15 and 275 volts. Similarly the six current testing circuits are divided into two groups of three circuits each; one, the ~~length~~ high current group, to be used where the current ranges from 10 to 300 amperes; and the other, the low current group, to be used where the current ranges from .01 to 10 ampers.

The three circuits of each group are lettered A, B and C respectively. The A circuits of each group run to the A element of the oscillograph; the B circuits, to the B element; and the C circuits, to the C element. Thus to each element four circuits may be connected in turn by means of the two pole, four way switch A, B or C; one, a high potential circuit; one, a low potential circuit; one, a high current circuit, and one, a low current circuit.

In the potential circuits, the potential reducing resistances are connected between the source and the double throw switches. Between the double throw switches and the oscillograph controlling switches are connected non-inductive adjusting and calibrating resistances of about 100 ohms maximum resistance. In the low potential circuits these resistances may be used as potential reducers where the emf. is less than 15 volts, all other resistance to be cut out of circuit. The principle function of these variable resistances,

however, consists in adjusting for any desired deflection, when obtaining a quantitative emf. registration. The constant emf. is supplied through a potential rheostat so that any emf. up to 10 volts may be used for calibration. The emf. is noted by the voltmeter and the current by the ammeter.

The actual value of the ordinate to the quantitative emf. registration is obtained by the formula:

$$E = RI_o + E_o$$

the meaning of which will be understood from the following: Suppose the adjusting resistance during any observation is R (must remain the same when obtaining the quantitative registration), the potential reducing resistance in circuit R, the calibrating emf. E_o, and the corresponding current I_o. Then

$$I_o = \frac{Eo}{R}$$

Moreover, if, during the registration of the emf. under investigation, at any instant when the current is I_o, the emf. is E, then also

$$Io = \frac{E}{R + r}$$

$$\text{whence } E = \frac{R + r}{r} \left(Eo \right)$$

$$\text{or since } r = \frac{Eo}{Io}$$

$$E = RIo + Eo$$

Since R is a definite known resistance, and since Io and Eo are read from the calibrating ammeter and voltmeter respectively, the ordinate to the quantitative registration is fully determined.

Referring to the current testing circuits, it will be seen that the shunts are connected between the middle points of the double throw switches, so that when the latter are thrown one way, the

shunts are placed in series with the sources, and when the others, they are placed in series with the constant current calibrating circuit. In series with each element is placed a non-inductive, adjusting resistance, having a maximum resistance of about 6 ohms. The one function of this resistance is to assist, in connection with a given shunt, to adjust for a maximum deflection.

To obtain a quantitative current registration, direct current is passed through the shunt of sufficient amount to produce a good deflection. The reading of the ammeter in the calibration circuit at once gives the value of the ordinate to this registration. When making quantitative current registration it is necessary to jumper the line under test so as to prevent arcing (especially if a heavy current is flowing) upon opening the circuit at the double throw switch when the latter is closed onto the calibrating circuit; in other words, no switch should be opened, when the current in the line is thereby interrupted.

Fig. 2 shows a drawing of the cabinet, which also is a table. The construction is as light as is compatible with rigidity. The finish is in oak. The cabinet stands 40 3/4 " high, including the roller castors. This is not so high as to prevent easy view of the tracing table of the oscillograph when mounted on the top of the cabinet. The cabinet top is fitted with a removable cover, immediately below which, contained in a box 6" deep, are located the twelve adjusting and calibrating resistances.

In the left of the cabinet, 2 3/4" back of the panel door, is mounted a slate post board. On this board are assembled the terminals of all the testing, calibration and auxiliary circuits, as in

indicated the drawing of fig. (3). The advantage gained in having all these terminals on one board, on one side of the cabinet, consists in leaving the other side free for the investigator to move about unhampered by the presence of wires.

The current terminal is a combination binding post. It consists of an ordinary post of the proper size, and a tapered projection onto which a conical receptacle of the same taper may be jammed. A short cable provided with one of these receptacles at each end serves as a jumper to maintain the current lines uninterrupted when the "current" double throw switches are opened.

In the rear end of the table is moubted a slate switchboard, clearing the inner edge of the panel door by 4 1/2". On this board, of which a detailed drawing is shown in fig. (4) and a photographic view in fig. 5, are assembled the twelve double throw switches, belonging to the twelve testing circuits. The heavy current switches are mounted at the end nearest the post board so as to minimize the amount of heavy wiring. Alongside each current switch are set two switch jaws, spaced to receive a carrier containing the shunt. This scheme allows the ready interchange of shunts, as the range of current alters. The leads which tap the shunts, are passed through holes in the board just a little to one side of each of the jaws.

The shunt carriers, designed for the high and low current shunts, are shown in detail in fig. 6. The carrier consists of two blades, one at each end, and of a size to fit the jaws on the switchboard. These blades are sweated into copper blocks between which the shunt proper is attached. Binding posts are mounted in each of the copper blocks. To these the terminals are attached which lead to the oscillograph. The two copper blocks are held rigidly together by two wooden strips, one on each side.

The shunt proper consists of manganin strip .021" thick where the current carrying capacity demands, but of manganin wire otherwise. The minimum length of shunt which can be adopted so as to not exceed a current carrying capacity of 1500 amperes per sq. in. is found to be 8 1/2". A strip of manganin 8 1/2" long, 1" wide, and .021" thick has a resistance of .006686 ohms. Whence the number of strips (N), and the width (B) of each, necessary to give a shunt of the required resistance R, is given by the formula:

$$NB = \frac{.006686}{R}$$

For shunts exceeding 5 amperes current carrying capacity, manganin strip of the thickness .021" is used. The data on the dimensions of these shunts to give the resistance called for in tables V, VI, VII and VIII, is shown in the following table.

TABLE IX

Manganin Strip			No. of	Resistance of	Current Range	
Length	Width	Thickness	Strips	Shunt	Amps.	Amps.
8.5	.18	.021"	1	.03671	2.25	5
"	36	"	1	.01836	5	10
"	72	"	1	.00918	10	20
"	1.45	"	1	.00459	20	40
"	1.45	"	2	.002298	40	80
"	1.45	"	4	.001149	80	160
"	1.45	"	6	.000574	160	320

In the front side of the cabinet, mounted 4 1/2" clear from the inner side of the panel door, is located the regulating board, a drawing of which and the apparatus mounted thereon, is shown in fig. 7, and a photographic view of same (while yet unfinished) in

fig. 8. This board is made of oak so as not to necessarily increase the weight of the cabinet. Arranged in a row along the top ~~of~~ are the handles of the twelve adjusting and calibrating resistances (which are located in a box immediately back of the board). The rheostats for the auxiliary circuits are shown mounted in the center of the board. The lantern rheostat is kept outside of the cabinet because of the heat which it liberates. In order that it may be connected in circuit, the two posts as indicated are provided. The field electromagnet switch is also mounted on this board. In the lower center part of the board is shown the resistance box, which slides through the board in the fashion of the drawer. This allows for the resistance to be readily inspected. To remove the box, however, the connections thereto must first be disconnected.

A detailed drawing of the resistance box, showing the resistance coils, the manner of mounting same, and the switching devices for shunting the resistances out of circuit, is shown in fig. 9. The resistances, seen in the photographic view of fig. 10, consists of #35 double silk covered manganin wire wound in parallel, in a single layer, on brass cylindrical bobbins from which the wire is insulated by three layers of linnen cloth. The parallel winding implies a potential of 800 volts, in the case of the largest coil, to exsist between two #35 wires side by side. Subjecting these resistances, however, to a pressure of 1000 volts, showed no intimation of break down. Further, since the wire is wound on a brass bobbin and ventilation is well provided for, the maximum current of .1 ampere will cause no undue ~~luating~~ heating. This experimentally was found to be true. The resistance of each coil is made exact, as called for, since this resistance enters as a multiplying factor in deter-

mining the ordinate to the quantitative emf. registration.

The manner of mounting the coils is clear from the drawing. Each of the potential circuits has its set of coils assembled one within the other. The coils are supported thus concentrically by means of spiders at each end. These spiders are partly cut away so as to create a ventilating space for the air around the inner coils to circulate.

The resistances are cut out of circuit by shunting them with a very low resistance. The terminals of each coil are brought out through insulating sleeving to brass blocks, well insulated from each other on a rubber strip. Attached to the inner side of each of these blocks is a spring. By pushing a switch key down, the springs of adjacent blocks are connected together, thus shunting the resistance out of circuit.

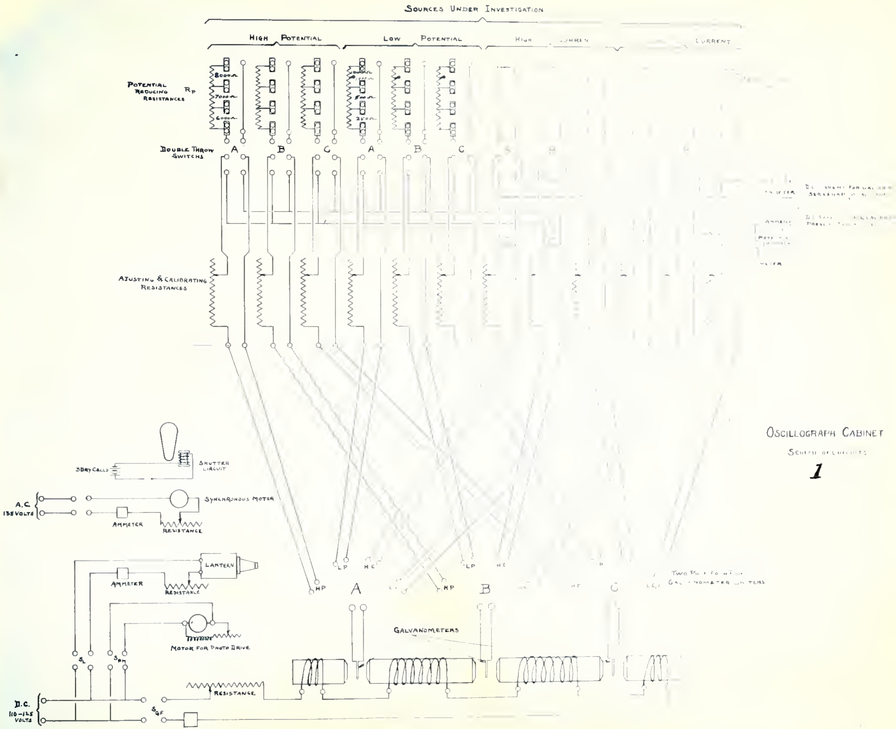
In fig. 11 is shown a drawing of the adjustable resistances, a photograph of which is also seen in fig. 10. The potential adjusting resistances consists of #26 double silk covered manganin wire, wound in parallel on rectangular brass bobbins from which the winding is insulated by two layers of linnen cloth. The insulation of the wire along the upper edge of the bobbin is removed by means of emery cloth. Along this portion of the wire, as thus bared, a contact is made to move, operated by a screw and nut. The contact bridges the circuit between the parallel winding.

The same size and style of bobbin and adjusting screw is used for the current adjusting resistances. However, since the total resistance required in this instance need only be six ohms, a simple loop of bared #26 wire is strung parallel to the top of the bobbin. The contact, as before, is made to bridge the circuit between the two wires.

A drawing of the top of the cabinet showing a disposition of the measuring instruments, is seen in fig. 12. The oscillograph is so placed that the belt driving the photographic attachment clears the edge. In front of the oscillograph are mounted the three controlling switches A, B and C. A detail drawing of this switch is seen in fig. 11. These switches are mounted on a slightly raised platform so that the necessary winding, somewhat complex, may be done in a manner to insure the best of insulation. The calibrating instruments are assembled in a row along the rear edge. The holes in the top of the cabinet for the passage of leads, are indicated by circles having crosses in them. All removable terminals are so arranged that they cannot slip back through the holes through which they pass.

All the interior wiring is run in insulated sleeving and bare parts are insulated with tape.

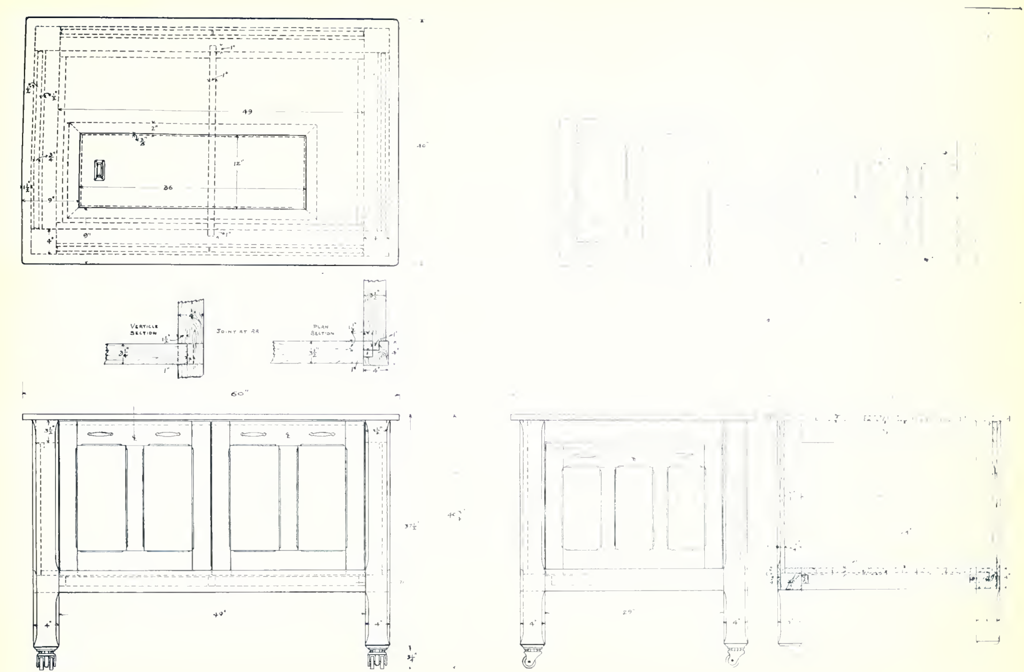
To carry out any investigation with the apparatus just described requires, to obtain the best satisfaction, at least two operators. One, however, need only be skilled in the manipulation of the oscillograph and the apparatus mounted in the cabinet.



Oscillograph Cabinet

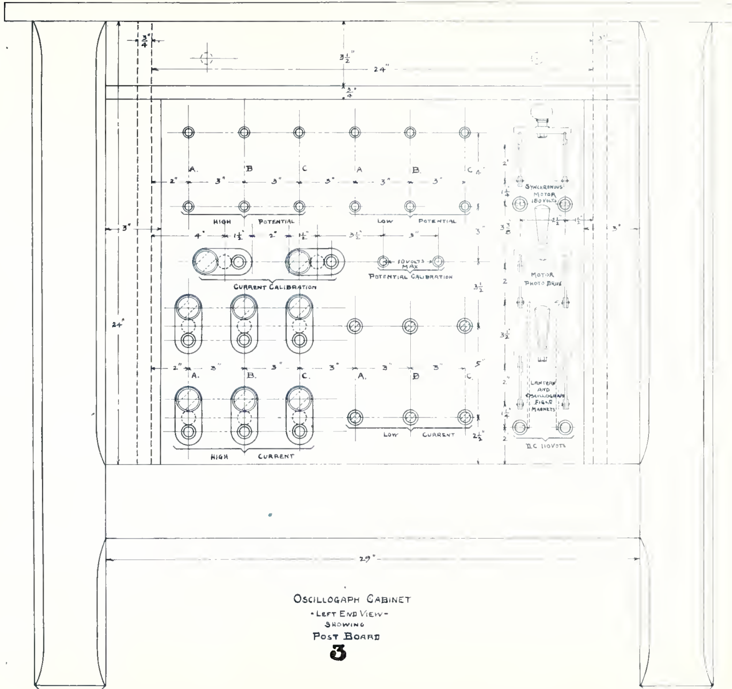
Scheme of Circuits

1

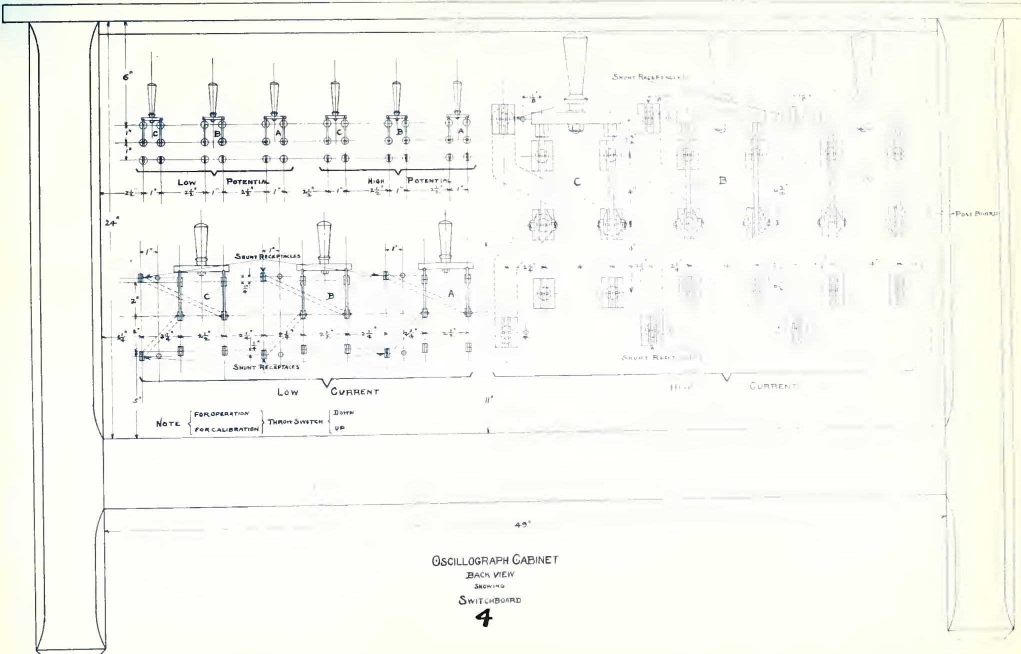


Cabinet for Oscillograph
AIT June, 1906
Scale ⅛" = 1'

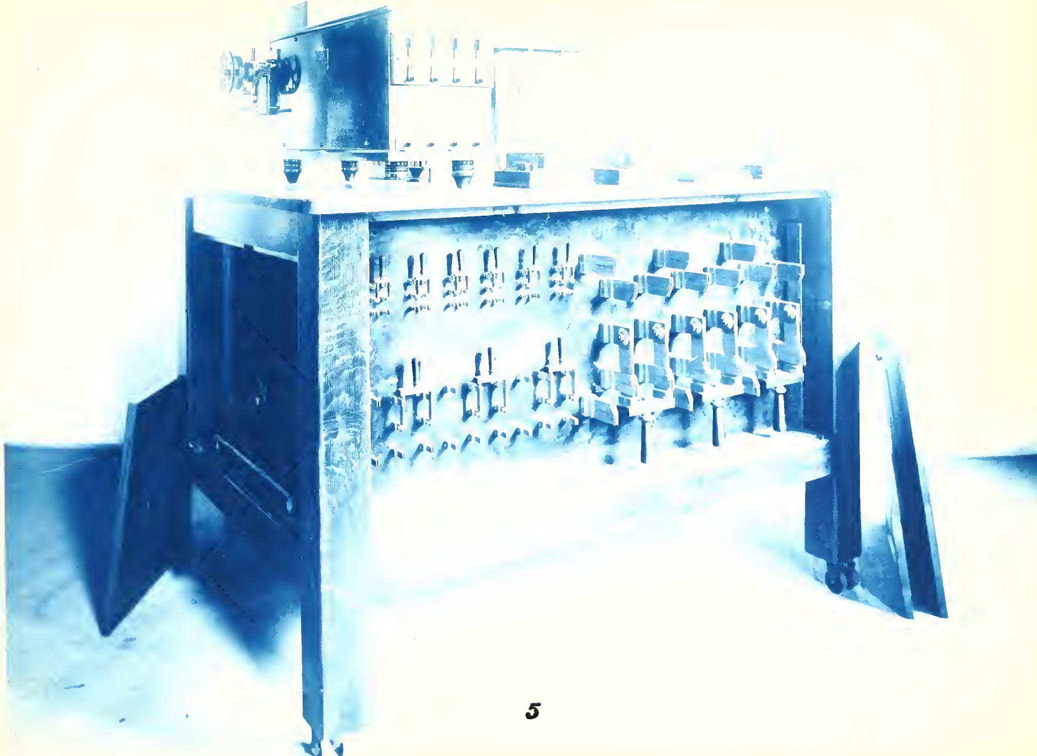
2



Oscillogaph Cabinet
- Left End View -
Showing
Post Board
3



OSCILLOGRAPH CABINET
BACK VIEW
SHOWING
SWITCHBOARD
4



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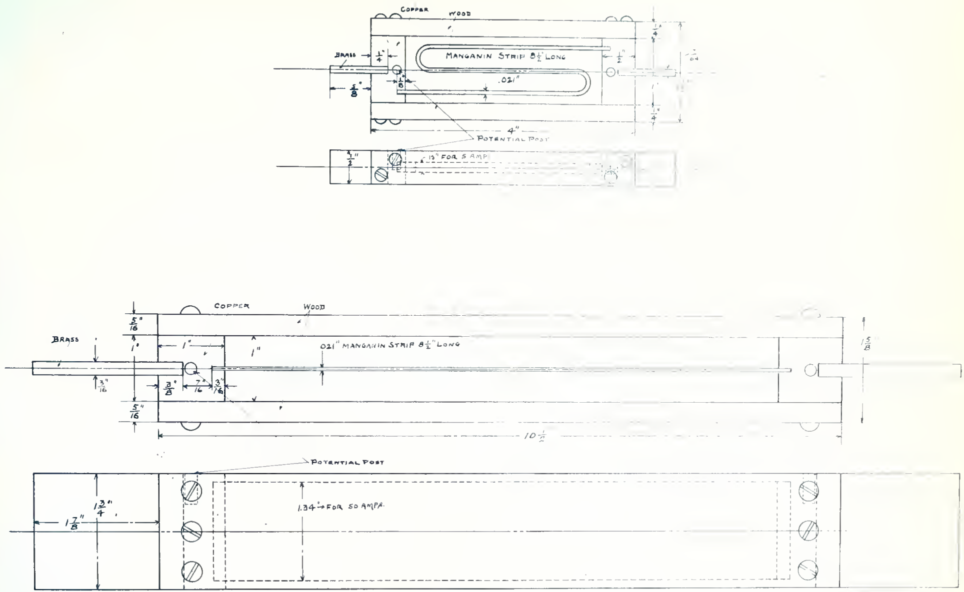
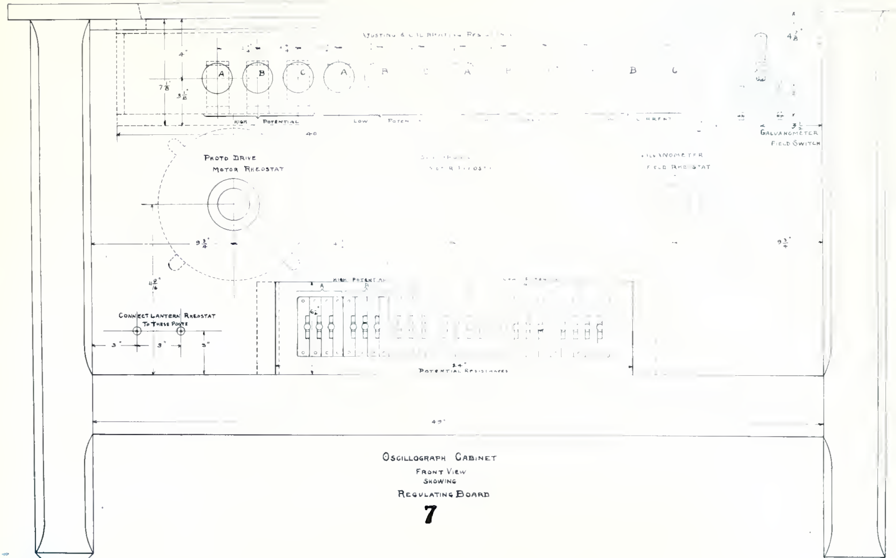


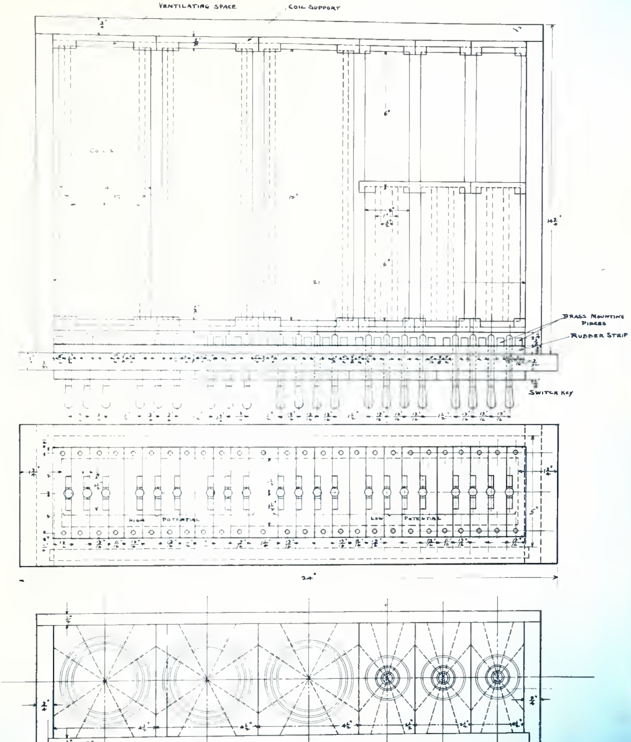
SHUNT CARRIERS
- FOR -
LOW AND HIGH CURRENT SHUNTS
6



Oscillograph Cabinet
Front View
Showing
Regulating Board

7

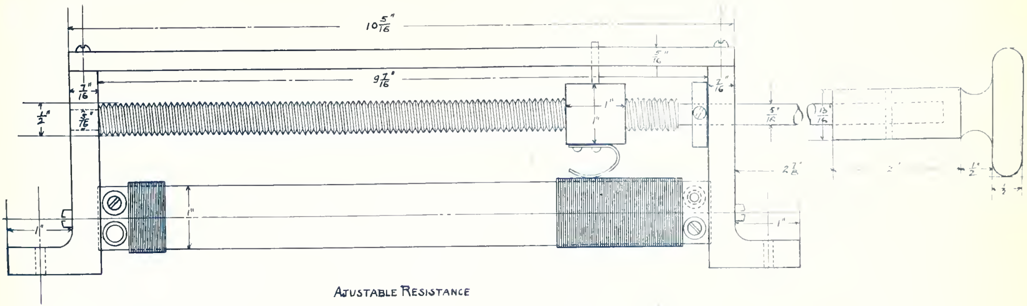
8



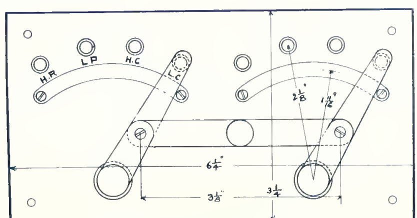
OSCILLOGRAPH CABINET
POTENTIAL RESISTANCE BOX

9

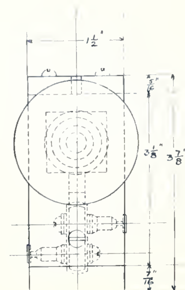
10



AJUSTABLE RESISTANCE

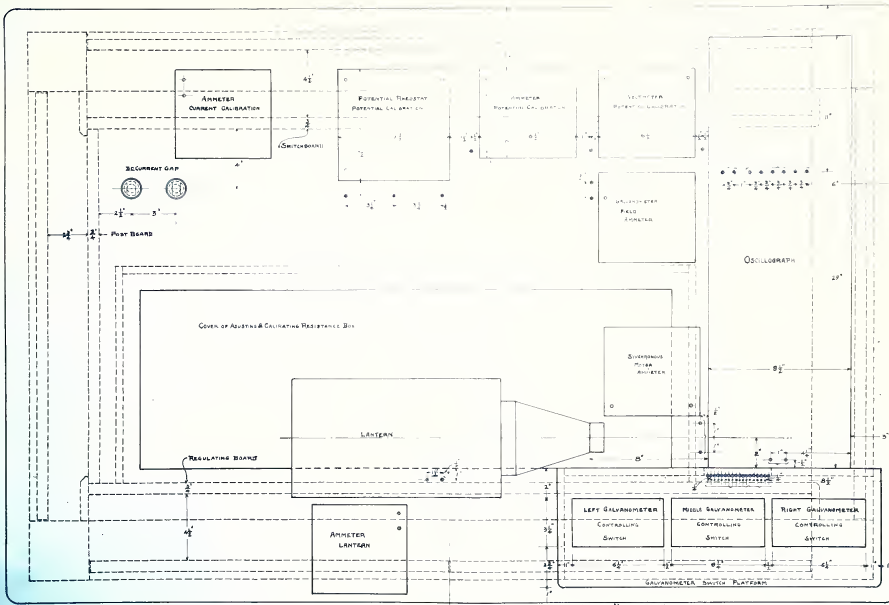


GALVANOMETER CONTROLLING SWITCH
A



END VIEW

11



Oscillograph Cabinet
Top View
Showing
Disposition of Apparatus
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